UNIT THREE

3 BASIC TOOLS OF ASTRONOMY

Introduction

This chapter deals with some basics of astrophysics. Astrophysics is only an extension of classical astronomy in the same sense as quantum mechanics and nuclear physics are extensions of classical physics. What is astronomy? **Astronomy is the science which deals with (size, position, motion and composition) celestial objects and their phenomena.** Astronomy is a term originated from two Greek words astron and nomos. Astron means star and nomos means law. Then what is astrophysics? **Astrophysics is a branch of astronomy that deals with the physical properties of celestial objects such as luminosity, size, mass, density, temperature and chemical composition and their origin and evolution.** Actually astrophysics is a child born from the marriage of physics and astronomy. Astronomy is an observational science and not an experimental science like other sciences because we cannot control the condition of experiments or event which are occurring in heavenly bodies. In astronomy the events occur automatically in stars, galaxies and interstellar medium and we observe them from earth. Hence the repetition of an experiment in other sciences is replaced by statistical study of large samples and changes in experimental conditions are taken into account by observations of a large variety of closely similar objects. Statistics thus plays an important role in the astronomical method. **The main source of information about heavenly bodies is the study of electromagnetic radiations emitted from them.**

Although astronomy based on observations rather than experiments, it is a science in the strictest sense of the word as opposed to the superstitious subject of astrology. In ancient times the same individuals practiced astronomy and astrology simultaneously and they were considered as one and the same. But after the discovery of telescopes astronomy grew as an observational science where as astrology did not follow the method of science and grew with belief and establishes customs. As a result astronomy and astrology drifted poles apart. Astrology claims to predict the future of men from the prevalent planetary positions among the stars. The entire edifice of astrology is build upon the movement of nine planets (Sun, Moon, Mercury, Venus, Mars, Jupiter, Saturn, Rahu and Ketu) across the sky spread over an angular separation of 18° on either side of ecliptic. If we consider this 18° width spread across the sky as a ribbon, it is called zodiac. The planets rahu and ketu were called as dark planets because they were responsible for eclipses. Now a days we know that rahu and ketu are not planets but they are geometrical intersection points of apparent path of moon and ecliptic. It is not wise to put an end without saying the famous words of Kepler who was the astrologer of Wallenstein palace. Kepler once said "Astrology is the foolish daughter of wise mother astronomy".

Stellar distance

Our primary aim in astronomy is to determine the distance of distant objects in the sky. This is necessary because for the determination of many other parameter like luminosity, brightness etc. The basic tool required is distance. But determining distance in astronomy has always been and continues to be difficult and associated with errors. There are so many methods available, but till now there is no consensus about which method is the best. The Stellar parallax is the probably the most accurate especially for determining the distances to stars.

Stellar parallax method

Parallax

Let us first see the meaning of parallax. Hold a pencil P at a distance from your eyes. Look at the pencil by closing the right eye and then left eye. The position of the pencil seems to change with respect to the background. This apparent shift (angle) is called parallax. The distance between points of observation (here the distance between left eye and right eye) L and R is called basis.

Stellar parallax

Stellar parallax is a measure of the star's distance. it is basically the angular measurement when the star is observed from two different locations on the earth's orbit. These two positions are generally six months apart and so the star will appear to shift its position with respect to the more distant background stars. The parallax P of the star observed is equal to half the angle through which its apparent position appears to shift. The larger the parallax (p), the smaller the distance (d) to the star.

Stellar parallax method

To measure the distance of a star, the star is photographed from the position A of the earth against the background of the far off stars. Repeat the observation after six months from the position B of the earth on the other end of the baseline. See figure below. From the observations the half angle subtended by the baseline AB can be measured. This gives the parallax

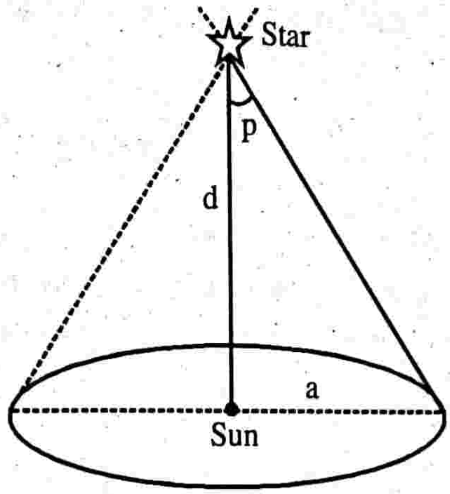

Figure 3.1

From the figure we have

$$\tan p = \frac{a}{d}$$

or
$$p = \frac{a}{d} \qquad (\because \ \text{p is very small})$$

$$d = \frac{a}{p} \qquad \text{..... (1)}$$

The distance $a\left(\frac{AB}{2}\right)$ is measured in metres. Usually the angle (p) is measured in radian. In the case of star the angle p is measured in seconds of arc. So we have to convert radian into seconds of arc.

We have
$$1^\circ = \frac{\pi}{180} \text{ radian.}$$

$$1 \text{ radian} = \frac{180}{\pi} \text{ degree}$$

or
$$1 \text{ radian} = \frac{180}{\pi} \times 60 \text{ minutes}$$

$$1 \text{ radian} = \frac{180}{\pi} \times 60 \times 60 \text{ seconds of arc}$$

$$1 \text{ radian} = \frac{180 \times 60 \times 60}{3.14158} \text{ seconds of arc}$$

$$1 \text{ radian} = 206, 265'' \text{ seconds of arc}$$

$$\therefore \quad 1 \text{ second of arc} = \frac{1}{206265} \text{ radian} = 4.848 \times 10^{-6} \text{ radian}$$

When $a = 1\text{AU} = 1.496 \times 10^{11}\text{m}$ and $p = 1''$

(1AU is the average distance from the earth to the Sun). Then the distance d is said to be one parallactic second (parsec). Parsec is symbolically written as pc

From eqn. 1, we have

$$1\,\text{pc} = \frac{1\text{AU}}{1''} = \frac{1.496 \times 10^{11}}{4.848 \times 10^{-6}}$$

$$1\text{ pc} = 3.08 \times 10^{16}\text{m}$$

Definition of Parsec

One parsec is defined as the distance at which arc length one AU substends an angle of $1''$.

From eqn. (1) we get

$$d = \frac{1}{p} \quad \text{When } a = 1$$

Now d is in parsecs and parallax p is in arc seconds. Thus, we can say the distance of star in parsecs in the reciprocal of its parallax p.

$$d = \frac{1}{p} \qquad \text{..... (2)}$$

For example if the measured parallax of a star is 0.01 arc second then the distance of the star is 100 pc.

Relation between AU, *l*y and pc

We have $1\text{AU} = 1.496 \times 10^{11}\text{m}$

This unit is used to measure very large distances within the solar system.

Light year is defined as the distance travelled by light in vacuum in one year.

$$s = vt = ct$$

$$1 \text{ light year} = 3 \times 10^{8} \times 365 \times 24 \times 60 \times 60$$

i.e, $$1\,ly = 9.46\times10^{15}\,\text{m}$$

This unit is used for measuring large distances of stars and galaxies.

$$1\text{pc} = 3.08\times10^{16}\,\text{m}$$

$$\frac{1ly}{1\text{AU}} = \frac{9.46\times10^{15}}{1.496\times10^{11}} = 6.32\times10^{4}$$

$\therefore$ $$1\,ly = 6.32\times10^{4}\,\text{AU}$$

$$\frac{1\text{pc}}{1ly} = \frac{3.08\times10^{16}}{9.46\times10^{15}} = 3.26$$

$\therefore$ $$1\text{pc} = 3.26\,ly$$

$$\frac{1\text{pc}}{1\text{AU}} = \frac{3.08\times10^{16}}{1.496\times10^{11}} = 2.05\times10^{5}$$

$\therefore$ $$1\text{pc} = 2.05\times10^{5}\,\text{AU}$$

$\therefore$ $$1\,\text{pc} > 1\,ly > 1\,\text{AU}$$

The parallax method is used only to measure distances up to 100 pc. This corresponds to a parallax of 0.01 arc second. This is because the angles smaller than 0.01 arc second are very difficult to measure from the earth due to the effects of the atmosphere. This limits the distance measured to about 100 pc. However, the satellite Hipparcos launched in 1989 was able to measure parallax angles to 0.001 arc seconds which corresponds to a distance of 1000 pc.

All known stars have a parallax angle smaller than 1 arc second. For example our second nearest star proxima centuari belongs to centaurus constellation is at a distance of 1.3 pc (4.22 ly) and corresponding parallax is $0.772''$. Another example is the star sirus which belongs α canis Majoris constellation is at a distance of 2.64 pc. (8.6 ly) which corresponds to a parallax of 0.379 arc seconds.

Parallax of some bright and near by stars and the corresponding constellation arc given below.

Note: Hipparcos is the abbreviation of high precision parallax collecting satellite and at the same time remembering great Greek astronomer Hipparchus.

Table 3.1: Nearest stars in the sky

No	Star	Parallax in arc second	Distance in pc	Constellation
1	Proxima centauri	0.772	1.3	Centarus
2	Alpha centauri A	0.741	1.35	Centarus
3	Barnards star	0.55	1.82	Ophichus
4	Wolf 359	0.418	2.39	Leo
5	Lalande 385	0.392	2.55	Ursa Major
6	Sirius A	0.379	2.64	Canis Major
7	UV ceti A	0.374	2.67	Cetus
8	Ross 154	0.336	2.97	Sagittarius
9	Ross 248	0.316	3.16	Andromeda
10	Epsilon Eridani	0.311	3.22	Eradinus
11	HD 217989	0.304	3.29	Piscis Austrinus
12	Ross 128	0.299	3.34	Virgo
13	L789-6A	0.291	3.44	Acquaris
14	61 cygni A	0.287	3.48	Cygnus
15	Procyon A	0.286	3.50	Canis Minoris
16	61 cygni B	0.285	3.51	Cygnus
17	HD 173740	0.284	3.52	Draco
18	HD 173739	0.280	3.57	Draco
19	GX Andromeda	0.280	3.57	Andromeda

We found that distances of stars up to 1000 pc $(3.08\times10^{17}\,\text{km})$ could be determined. But these are all relatively close stars. Most of the stars in the galaxy are too far away for parallax measurements to be taken. So we discuss some other methods of distance measurements in astronomy.

This method is based on the regular variation of brightness (or luminosity) of stars. The stars whose brightness vary at regular intervals of time is called variable stars or pulsating stars (pulsars).

There are two types of variable stars particularly useful in determining distances. These are Cepheid variable stars and RR Lyrae variable stars. These stars change their diameters over a period of time. This period of time can be measured very accurately. Using Period-luminosity relationship we can calculate the luminosity. By comparing the luminosity, which is a measure of the intrinsic brightness of the star with the brightness it appear to have in the sky, its distance can be calculated from the luminosity-brightness relation which contains the distance.

Using Cepheid star as the reference, distances about 18.4 millions parsecs have been determined. Using RR Lyrae stars as the reference, distances about 0.61 million parsec have been determined.

Another method of distance determination is that of spectroscopic parallax. In this method we take the spectra of stars.

From the spectral classification, we will be able to calculate their intrinsic luminosity. Then it will be compared with its apparent brightness to determine its distance.

There are other distance determination methods for the objects farthest away from us such as other galaxies. They are Tully Fisher method, Hubble law method etc.

We conclude this section by saying that all these methods do not produce exact results. The error associated is in between 10% to 25%. Sometimes it may go upto 50%. For example distance of a star is measured 10000 pc. Suppose it has 25% error. This means that star can be found any where between $10000 \pm 10000 \times \frac{25}{100}$

i.e., in between 7500 pc and 12500pc (in between 2.3×10^{20}m and 3.85×10^{20}m).

Brightness and luminosity

There are millions and millions of stars in the sky. Out of which the total number of stars visible to the naked eye in the whole sky is only about 5000. Others can be seen through telescopes. Most of the stars are powered by the same process that fuels the Sun. This does not mean that they are all alike. Stars differ in their size, mass, luminosity etc. One of the most important characteristics is their luminosity(L). **The luminosity of a star is the total amount of radiant energy emitted per second from the surface of a star.** It is measured in watts (W) or as a multiple of the Suns luminosity denoted by $L_\odot$ (a circle with a dot indicates Sun in astronomy). However luminosity of a star cannot be measured directly. This is because what we can measure on earth is the amount of light reaching on earth. So we introduce a term called apparent brightness or simply brightness of a star denoted by b. **The amount of light energy reaching the earth per unit area in unit time is called brightness.**

It is measured in Wm^{-2}. The brightness (b) depends on the luminosity (L) and the distance of the star(d). This is as follows.

The light received per unit area in unit time on earth = b

If the star is at a distance of d from the earth. The star would emit light in all directions covering a total area of $4\pi d^2$.

$\therefore$ The total energy that can be received by covering the whole sphere of area

$$4\pi d^2 \text{ in unit time } = b\cdot 4\pi d^2.$$

This is nothing but the light energy emitted by the star in unit time called luminosity.

i.e.

$$L = b4\pi d^2$$

or

$$b = \frac{L}{4\pi d^2} \quad \text{..... (2)}$$

This is the relation between luminosity, brightness and distance.

Astronomers measure star's brightness with light sensitive detectors and this procedure is called photometry.

Example 1

The star Sirius A has luminosity 97.28×10^{26} W, and is at a distance of 8.6 *ly*. Calculate its apparent brightness.

Solution

$$L = 97.28\times10^{26}\,\text{W}, \quad d = 8.6\ ly = 8.6\times9.46\times10^{15}\,\text{m}$$

The apparent brightness, $b = \dfrac{L}{4\pi d^2}$

$$b = \frac{97.28\times10^{26}}{4\times3.14\times(8.6\times9.46\times10^{15})^2}$$

$$b = \frac{97.28\times10^{26}}{4\times3.14\times8.14^2\times10^{32}}$$

$$b = \frac{97.28}{4\times3.14\times66.3}\times10^{-6}$$

$$b = 1.17\times10^{-7}\,\text{Wm}^{-2}$$

Example 2

The luminosity of Sun is 3.83×10^{26} W. What is its apparent brightness.

Solution

$$L = 3.83\times10^{26}\,W \qquad d = 1\,AU = 1.496\times10^{11}\,m$$

Using $$b = \frac{L}{4\pi d^2} = \frac{3.83\times10^{26}}{4\times3.14\times1.496^2\times10^{22}}$$

$$b = 1363\ Wm^{-2}$$

Example 3

The star aldebaran which belongs to Taurus is at a distance of $65.11\,ly$ has luminosity $518L_\odot$. Calculate its brightness.

Solution

$$d = 65.11\ ly = 65.11\times9.46\times10^{15}\,m = 6.16\times10^{17}\,m$$

$$L = 518L_\odot = 518\times3.83\times10^{26}\,W$$

$$L = 1.98\times10^{29}\,W$$

Using $$b = \frac{L}{4\pi d^2}$$

$$b = \frac{1.98\times10^{29}}{4\times3.14\times6.16^2\times10^{34}}$$

$$b = 4.15\times10^{-6}\,Wm^{-2}$$

Luminosity, brightness and distance of stars in terms of that of Sun's.

We have $$L = 4\pi d^2 b$$

For the Sun $$L_\odot = 4\pi d_\odot^2 b_\odot$$

$$\therefore \qquad \frac{L}{L_\odot} = \left(\frac{d}{d_\odot}\right)^2\left(\frac{b}{b_\odot}\right) \qquad \text{..... (3)}$$

Here what we require is the distance of star measured in terms of earth-sun distance and brightness of star measured in terms of brightness of the sun with respect to earth. So we get the luminosity of the star in terms of $L_\odot$.

Example 4

Consider two stars A and B. Star A be at a distance half that of B and appear twice as bright as B. Compare their luminosities.

Solution

$$d_A = \frac{d_B}{2}, \; b_A = 2b_B$$

Using $L = \pi d^2 b$

$$\therefore \quad \frac{L_A}{L_B} = \frac{d_A^2 b_A}{d_B^2 b_B} = \left(\frac{d_A}{d_B}\right)^2 \cdot \left(\frac{b_A}{b_B}\right)$$

$$\frac{L_A}{L_B} = \left(\frac{1}{2}\right)^2 \cdot 2 = \frac{1}{2}$$

$$L_A = \frac{L_B}{2} \text{ or } L_B = 2L_A$$

Though star B is twice luminous than A, it appears to be less brighter.

Example 5

Consider two stars A and B. Star A appears to be half as bright as B and distance of A is two times that of B. How much is the luminosity of star A compared with respect to star B.

Solution

$$b_A = \frac{1}{2} b_B, \quad d_A = 2d_B$$

Using $L = \pi d^2 b$

$$\frac{L_A}{L_B} = \frac{d_A^2}{d_B^2} \frac{b_A}{b_B} = \left(\frac{d_A}{d_B}\right)^2 \cdot \left(\frac{b_A}{b_B}\right) = 2^2 \cdot \frac{1}{2} = 2$$

$$\therefore \quad L_A = 2L_B$$

Magnitudes of stars

We could see that the apparent brightness of a star differs from its luminosity.

The apparent brightness depends on its luminosity as well as on the distance of star from us. Based upon the measurements of apparent brightness of stars, a measurement scale had been developed called magnitude. It is denoted by m. During the second century B.C, Hipparchus (Greek astronomer) classified the naked eye stars into six magnitudes according to their apparent brightness. He catalogued nearly 1000 stars. The brightest star is assigned magnitude one (m = 1). The star of half as bright as first magnitude is called as second magnitude star (m = 2) and so on to the sixth magnitude star which are faintest star in the sky. In other words we can say that the first magnitude star is two times brighter than second magnitude star. The second magnitude star is two times brighter than third magnitude star. So the first magnitude star is 2^2 times brighter than third magnitude star. As there are six magnitudes, we can say that first magnitude star is 2^5 times brighter than sixth magnitude star.

In about 1830 William Herschel by his experiment on Stellar photometry determined that stars in one magnitude class are 2.512 times more brighter than the stars in the next higher magnitude class.

i.e. $$\frac{\text{Brightness of first magnitude star}}{\text{Brightness of second magnitude star}} = (2.512)^{2-1}$$

$$\therefore \quad \frac{\text{Brightness of first magnitude star}}{\text{Brightness of sixth magnitude star}} = (2.512)^{6-1} = (2.512)^5 = 100$$

Let b_1 be the brightness of first magnitude star and b_6 be the brightness of sixth magnitude star, the above relation can be written as

$$\frac{b_1}{b_6} = (2.512)^5 = (2.512)^{6-1} = (2.512)^{m_6 - m_1}$$

or in general $$\frac{b_1}{b_2} = (2.512)^{m_2 - m_1}$$

i.e. $$\frac{b_1}{b_2} = (100)^{\frac{m_2 - m_1}{5}} \qquad \left(\because \quad (100)^{\frac{1}{5}} = 2.512\right)$$

Taking log on both sides, we get

$$\log \frac{b_1}{b_2} = \frac{(m_2 - m_1)}{5} \log 100 = \frac{(m_2 - m_1)}{5} \times 2$$

$$\therefore \qquad m_2 - m_1 = 2.5 \log \frac{b_1}{b_2}$$

$$\text{or} \qquad m_2 - m_1 = -2.5 \log \frac{b_2}{b_1} \qquad \text{..... (4)}$$

This is the relation between apparent brightness and magnitude.

Another form of the relation between apparent brightness and magnitude

We have $\frac{b_1}{b_2} = (2.512)^{m_2 - m_1}$

Taking log on both sides, we get

$$\log\left(\frac{b_1}{b_2}\right) = (m_2 - m_1)\log 2.512$$

$$\log\left(\frac{b_1}{b_2}\right) = (m_2 - m_1) \times 0.4$$

$$\therefore \qquad \frac{b_1}{b_2} = 10^{0.4(m_2 - m_1)} \qquad \text{..... (5)}$$

If $b_1 = b_0$, the apparent brightness of zero magnitude star i.e $m_1 = 0$. From equation 4, we get

$$m_2 = -2.5 \log \frac{b_2}{b_0}$$

In general $\qquad m = -2.5 \log \frac{b}{b_0} \qquad$ ..... (6)

The star Vega (Abhijith) is of zero magnitude and it's brightness measured is $b_0 = 2.52 \times 10^{-8}\,\mathrm{Wm^{-2}}$

The apparent magnitudes of some stars and planets are given below.

Table 3.2: Some objects in the sky and their magnitudes

No	Object	Magnitude (m)
1	Sun	–26.7
2	Full moon	–12.6
3	Venus	–4.4*
4	Jupiter	–2.6*
5	Sirius A	–1.44
6	Sirius B	+8.66
7	Faintest observable star	+23

Note: * When brightest

In the table 3 given below magnitude difference and brightness ratio are shown.

Table 3.3: Magnitude difference and brightness ratio

Magnitude difference $m_2 - m_1$	**Brightness ratio** $\frac{b_1}{b_2} = 10^{0.4(m_2 - m_1)}$
0.0	1.0
0.1	1.1
0.2	1.2
0.3	1.3
0.4	1.45
0.5	1.58
0.6	1.74
0.7	1.91
1	2.51(2)
2	6.31
3	15.85
4	39.8
10	10000
15	1000000
20	100000000

Example 6

The Sun has a magnitude of –26.7 and the full moon has a magnitude of –12.6. Find the apparent brightness of Sun compared to that of full moon.

Solution

$$m_{\odot} = -26.7$$

$$m_{moon} = -12.6$$

Using $m_2 - m_1 = 2.5 \log \frac{b_1}{b_2}$

We have $m_{moon} - m_{\odot} = 2.5 \log \frac{b_{\odot}}{b_{moon}}$

$$-26.7 - -12.6 = 2.5 \log \frac{b_{\odot}}{b_{moon}}$$

$$\frac{-14.1}{2.5} = \log \frac{b_{\odot}}{b_{moon}}$$

$$\log \frac{b_{\odot}}{b_{moon}} = -5.64$$

or $$\frac{b_{\odot}}{b_{moon}} = 10^{-5.64} = 2.29 \times 10^{-6} = \frac{1}{4.37 \times 10^5}$$

$\therefore$ $$b_{\odot} = \frac{b_{moon}}{4.37 \times 10^5}$$

This shows that, though the luminosity of sun is greater than twice the luminosity of moon, its brightness is about 1 millionth of that of moon.

Example 7

Compare the apparent brightness of Sun and the star Sirius A. $m_{\odot} = -26.7$ and $m_{sirius} = -1.44$

Solution

$$m_{\odot} = -26.7\,, \quad m_{sirius} = -1.44$$

We have $m_2 - m_1 = 2.5 \log \frac{b_1}{b_2}$

$$m_{sirius} - m_{\odot} = 2.5 \log \frac{b_{\odot}}{b_{sirius}}$$

$$-1.44 - -26.7 = 2.5 \log \frac{b_{\odot}}{b_{sirius}}$$

$$\frac{25.26}{2.5} = \log \frac{b_{\odot}}{b_{sirius}}$$

$$10.104 = \log \frac{b_{\odot}}{b_{sirius}}$$

$$\therefore \quad \frac{b_{\odot}}{b_{sirius}} = 10^{10.1} = 1.259 \times 10^{10}$$

This problem shows that even though Sirius is much luminous than sun ($L_{sirius} = 25.4 L_{\odot}$), it apparent brightness is $\frac{1}{1.259 \times 10^{10}}$ times fainter than the sun.

Absolute magnitude (M)

The apparent magnitude of a star does not tell us whether a star is actually bright or not. It tells us only about the apparent brightness. The apparent brightness of a star depends on the luminosity and the distance of the star. Of two stars are at the same distance their brightness are proportional to their luminosities. As stars are at different distances, their apparent brightness do not provide their luminosities. If we know the actual distances of stars, we can compare their luminosities by referring them to any chosen distance from us. For such a comparison of luminosities of stars, astronomers have chosen a standard distance of 10 parsecs (32.6 light years). The magnitude of the star is then called the absolute magnitude (M). **Thus the absolute magnitude (M) of a star has been defined as its apparent brightness if it were placed at a standard distance of 10 parsecs.** The absolute magnitude of a star, therefore depends on its actual brightness not on its actual distance.

Relation between apparent magnitude, absolute magnitude

Consider a star whose apparent brightness is b_1 and apparent magnitude m at a distance d. If the same star is at a distance D, let its apparent brightness be b_2 and apparent magnitude M.

From equation 5, we have

$$\frac{b_1}{b_2} = 10^{0.4(M-m)} \qquad \text{..... (7)}$$

From equation (2), the apparent brightness is

$$b = \frac{L}{\pi d^2}$$

Thus
$$b_1 = \frac{L}{\pi d^2}$$

and
$$b_2 = \frac{L}{\pi D^2}$$

Luminosity is same since only one star.

$$\therefore \quad \frac{b_1}{b_2} = \frac{D^2}{d^2}$$

Put this in equation (7), we get

$$\frac{D^2}{d^2} = 10^{0.4(M-m)}$$

Taking log on both sides we get

$$2(\log D - \log d) = 0.4(M-m)$$

$$\therefore \quad M - m = 5(\log D - \log d)$$

When $D = 10\text{pc}$, M is called the absolute magnitude

$$M - m = 5(\log 10 - \log d) = 5(1 - \log d)$$

or
$$m - M = 5(\log d - 1) \qquad \text{..... (8)}$$

This is the relation between apparent magnitude m, absolute magnitude M and distance d.

The quantity m – M, depends only on d, is called the distance modulus. Knowing the distance modulus the actual distance of star can be calculated from equation 8.

The absolute magnitude of the normal stars lie between –10 to +20. The range corresponds to a brightness ratio of about 10^{12}.

Example 8

The star Sirius A is at a distance of 2.63 pc and has an apparent magnitude of–1.44. Calculate its absolute magnitude.

Solution

$d = 2.63 pc$, $m = -1.44$

Using $$m - M = 5(\log d - 1)$$

$$\therefore \quad M = m - 5(\log d - 1)$$

$$M = -1.44 - 5(\log 2.63 - 1)$$

$$M = -1.44 - 5(0.42 - 1)$$

$$M = -1.44 - 5 \times -0.58$$

$$M = -1.44 + 2.9$$

$$M = -1.46$$

Example 9

The Sun has an apparent magnitude of -26.7. Calculate its absolute magnitude

Solution

$$m = -26.7 \quad d = 1 AU = \frac{1.496 \times 10^{11}}{3.08 \times 10^{6}} pc = 4.86 \times 10^{-6} pc$$

Using $$m - M = 5(\log d - 1)$$

$$\therefore \quad M = m - 5(\log d - 1)$$

$$M = -26.7 - 5(\log 4.86 \times 10^{-6} - 1)$$

$$M = -26.7 - 5 \times (-5.31 - 1)$$

$$M = -26.7 + 31.6$$

$$M = 4.9$$

Example 10

The star Vega belongs to Lyra constellation has an apparent magnitude zero is at a distance of 25.3 *ly*. Calculate its absolute magnitude.

Solution

$$m = 0,\ d = 25.3ly = \frac{25.3}{3.26}pc = 7.76pc$$

Using $$m - M = 5(\log d - 1)$$

$\therefore$ $$M = m - 5(\log d - 1)$$

$$M = 0 - 5(\log 7.76 - 1)$$

$$M = -5 \times 0.11 = 0.55$$

Example 11

The Betelgeuse belongs to Orion constellation has an apparent magnitude of 0.45 and absolute magnitude -5.14. Calculate its distance in light years.

Solution

$$m = 0.45, \quad M = -5.14$$

Using $$m - M = 5(\log d - 1)$$

$$0.45 - -5.14 - 5(\log d - 1)$$

$$\frac{5.59}{5} = \log d - 1$$

$\therefore$ $$\log d = 1 + \frac{5.59}{5} = 1 + 1.118 = 7.118$$

$$d = 10^{2.118} = 131.22pc$$

$$d = 131.22 \times 3.26\ ly$$

$$d = 427.7ly$$

Colour and temperature of stars

When we look up into the clear sky at night with naked eye we see several stars. All of them are generally white. This colour varies from person to person. This is because eye does not recognize colour at low light levels. This why at night with the naked eye we see only shades of grey, white, pale yellow etc. Moreover the most important factor determining the colour of a star you see is you-the observer. It is purely a matter of physiological and psychological influences. What one observer describes as a blue star another may describe as a white star or one may see an orange star, while another observes the same star as yellow. You might even observe a star to have different colour when using different telescopes or magnifications and atmospheric conditions certainly have a role to play. But there are some exceptions to these. A few stars exhibit distinct colours. For example Betelgeuse (α Orionis) and Antare (α Scorpi) are definitely red, Capella (α Aurigae) is yellow and Vega (α Lyrae) is steely blue. However in the case of naked eye stars, there is no much variation in colour. The scenario will be different when you look at stars with telescope, there seems to be much variations in colours.

The colour of a star is determined by its surface temperature. A red star has a lower temperature than that of a yellow star, which in turn has a lower temperature than that of a blue star etc. **The relation between colour and temperature of a star is explained by Wien's displacement law. According to the law**

$$\lambda_m T = \text{Constant} = 2{,}900{,}000 \text{ nmK} \qquad \text{..... (9)}$$

where λ_m is the wavelength corresponding to maximum intensity and T is the temperature. This law states that low temperature stars emit most of their energy in the red to infrared part of the spectrum, while much hotter stars emit in the blue to ultraviolet part of the spectrum. When stars emit energy in the ultraviolet or infrared region we cannot see them. The low temperature stars make up about 70% of the stars in our galaxy but you would never ever see them.

An important point to notice here is that hotter objects emit more energy ($\varepsilon \propto T^4$) at all wavelengths due to the higher average energy of all the photons. The three graphs shown below demonstrate how the light from three different stars is distributed depending on the star's temperature.

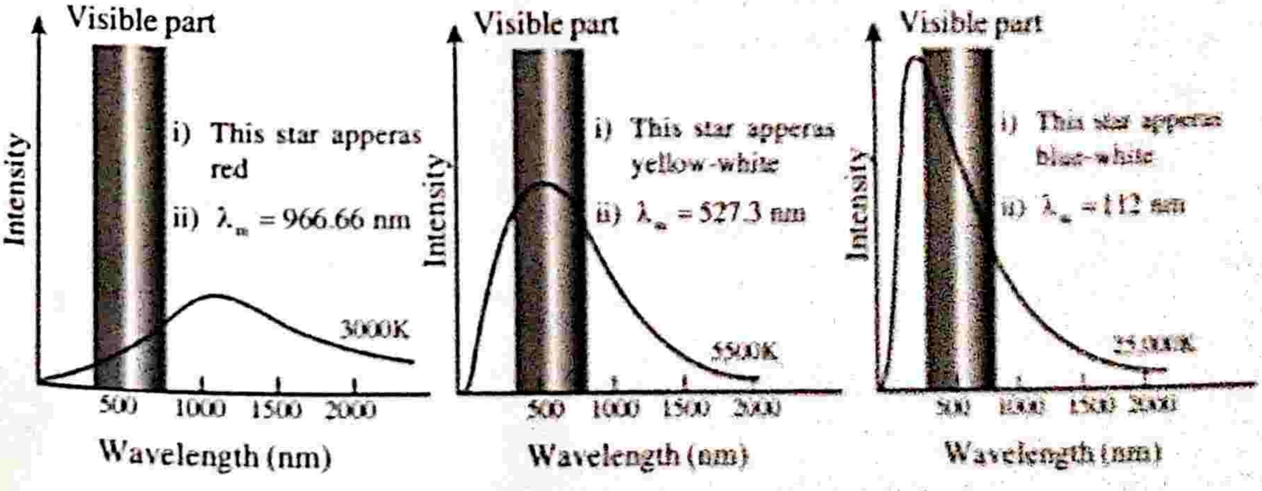

Figure 3.2: Relation between colour and temperature

Another interesting thing to observe is that a few stars are so hot, possibly in millions of degrees, emit X-rays. These are neutron stars.

Note: When we say about star's temperature it refers to its surface temperature.

Temperature of stars not only enables us to determine its colour but also helps to determine many other characteristics. One scientific description of a star's colour is based on the Stellar classification. Another term commonly used by astronomers in association with star's colour is colour index.

Example 12

Two stars α Canis Majoris and 0 Ceti, have a temperature of 9200K and 1900K respectively. What are their peak wavelengths?

Solution

$$T = 9200\text{K for } \alpha \text{ Canis Majoris}$$

We have $$\lambda_{max} = \frac{2,900,000}{T}\text{nm}$$

$$\lambda_{max} = \frac{2,900,000}{9200} = 315\text{nm}$$

This wavelength is in the ultraviolet region.

$$T = 1900\text{K for 0 Ceti}$$

$$\lambda_{max} = \frac{2900000}{1900} = 1526\text{nm}$$

This wavelength is in the infrared region.

Example 13

The mysterious star Zubeneschamali belongs to Libra constellation has a temperature of 11,000K. What is its peak wavelength?

Solution

$$T = 11,000\text{K}$$

We have $$\lambda_n = \frac{2,900000}{T}\text{nm}$$

$$\lambda_n = \frac{2,900000}{11,000} = 263.6\text{nm}$$

It is one of the rare green coloured stars.

Size and mass of stars

When we look at stars they seem to be like point light sources since they are several light years away from us. So how do we determine the size of a star is our concern now. Knowing the luminosity (L) and surface temperature (T) of a star we can easily find out the size of a star. Luminosity of a star is determined by knowing apparent brightness (b) and its distance d using the formula $L = 4\pi d^2 b$. The temperature of a star can be calculated from the spectra given out by the star using $\lambda_m T = 0.0029\,\text{mK}$ knowing L and T, how can we determine the size of a star. For this we make use of Stefan's law. According to this law the energy emitted per unit area in one second is proportional to the fourth power of the temperature T. The energy emitted per unit area in unit time is called energy flux (F). Thus according to Stefan's law

$$F \propto T^4$$

or
$$F = \sigma T^4 \qquad \text{.....(10)}$$

The constant of proportionality σ is called Stefan's constant and its value is given by

$$\sigma = 5.67 \times 10^{-8}\,\text{Wm}^{-2}\text{K}^{-4}$$

Relation between flux, luminosity and radius

Consider a star spherical in shape with a radius R. Its surface area is $4\pi R^2$. From the definition of luminosity, we have

$$L = \frac{\text{Energy emitted}}{\text{time}}$$

or
$$L = \frac{\text{Energy emitted} \times \text{Area}}{\text{Area} \times \text{time}}$$

By definition
$$\frac{\text{Energy emitted}}{\text{Area} \times \text{time}} = \text{Energy flux (F)}$$

$\therefore$
$$L = F \times \text{Area} = F \cdot 4\pi R^2 \qquad \text{.....(11)}$$

This is the relation between L, F and R. Substituting for F

$$L = \sigma T^4 4\pi R^2$$

i.e.
$$L = 4\pi R^2 \sigma T^4 \qquad \text{.....(12)}$$

Knowing L, σ and T, the size of the star can be calculated.

Note: Most of the stars are spherical in shape, a few are not.

The equations 10 and 12 tell us that, a cold star has low flux (eqn. 10), but it may have large luminosity if radius is large (eqn. 12). Similarly a hot star will have low luminosity it has a small radius. This implies that temperature alone cannot indicate how luminous a star will be, the radius is also needed.

Suppose we want to compare the size (radius) of a star with reference to size of the sun.

We have $L = 4\pi R^2 \sigma T^4$

$$\therefore \qquad L_\odot = 4\pi R_\odot^2 \sigma T_\odot^4$$

Thus
$$\frac{L}{L_\odot} = \left(\frac{R}{R_\odot}\right)^2 \left(\frac{T}{T_\odot}\right)^4$$

or
$$\frac{R}{R_\odot} = \left(\frac{L}{L_\odot}\right)^{\frac{1}{2}} \left(\frac{T_\odot}{T}\right)^2 \qquad \text{..... (13)}$$

Example 14

The star aldebaran belongs to taurus constellation has a temperature of about 3910K and luminosity of about 518 $L_\odot$. What is its size with reference to that of the Sun? $T_\odot = 5800K$.

Solution

$T = 3910K \qquad L = 518 L_\odot$

We have
$$\frac{R}{R_\odot} = \left(\frac{T_\odot}{T}\right)^2 \left(\frac{L}{L_\odot}\right)^{\frac{1}{2}}$$

$$\frac{R}{R_\odot} = \left(\frac{5800}{3910}\right)^2 (518)^{\frac{1}{2}} = 2.2 \times 22.76$$

$$\therefore \qquad R = 50.1\, R_\odot$$

In table 4 given below some giant and supergiant naked eye stars with size, luminosity and distance are shown

Table 3.4

No	Star	Radius in AU	Distance in ly	Luminosity in $L_{\odot}$
1	α -Herculus	2	400	7244 - 9333
2	ψ1 -Aurigae	2.88	4300	11,000
3	η -Persei	2	1300	4000
4	VV Cephei	8.8	2000	2×10^5
5	KQ Puppis	8.8	3361	>9870

Stellar constituents

Here we discuss about what stars are made of. A star is an enormous sphere of hot gases. The gas is composed of hydrogen, helium and some other elements (metals). Astronomers call every element other than hydrogen and helium a metal. The composition is usually about 75% of hydrogen, 24% helium and the remainder metals. This ratio may change, however very old stars are nearly all hydrogen and helium with tiny amount of metals and very few stars can contain 2-3 % metals.

The energy needed to create and maintain a star is produced within the star by nuclear fusion. For this a very high temperature and a strong gravitational fields are required. It is due to very large mass, strong gravitational fields are present. The temperature at the centre of star may be about 10 million kelvin. This results in huge pressure at the centre of the star. This huge pressure and enormous heat trigger nuclear reaction at the centre of the star. This nuclear reaction converts hydrogen into helium releasing small amount of energy when billions of such reactions takes place producing substational amount of energy, which makes a star shine.

This nuclear reaction continues for millions and million of years till all hydrogen are exhausted. The by-product of this nuclear reaction is helium when helium present is in abundance and under suitable conditions (higher temperature and a large mass), helium undergoes nuclear reactions at the core of the star. After a very long time the by-product this reaction which will be in abundance. If conditions are favourable carbon too will initiate nuclear fusion and the process continues. At each stage the temperature required is much greater than the previous stage. If this condition is not satisfied, at any stage further reaction will not occur. This shows that burning of hydrogen and helium are the source of power for nearly all the stars that we see. The mass of the star will determine how the reaction will proceed.

Stellar spectra

The spectrum given out by a star is called stellar spectrum. The stellar spectra plays an important role in astrophysics. This is because by analysing the spectra we can determine several parameters of the star such as its temperature, colour, distance, in which direction it is moving, whether it is rotating or not. In addition to these we can infer its age, mass, how long will it live and so on. Another important aspect is the spectral classification of stars.

To get solar spectrum what we need is a spectroscope, a prism or a diffraction grating a telescope and an eye piece. Using the spectroscope mounted at the eye piece end of a telescope, light from a star can be collected and photographed. Usually star emits different colours. The prism or diffraction grating helps us to disperse different colours. The result we obtain is called a spectrum.

The spectrum contains emission lines as well as absorption lines. Emission lines are due to emission of photon when particles jump from excited states to lower states. When the light from inner part of star passes through outer most cooler layer known as reversing layer some wavelengths are absorbed, depending upon the elements present in the reversing layer give rise to absorption lines. Absorption lines are indications of the elements present in the star. The factor that determines whether an absorption line will arise is the temperature of star's atmosphere. A hot star will have different absorption lines than a cool star. By examining the spectrum and measuring various aspects of the absorption lines the classification of a star is determined. Analysis of the structure of absorption lines gives information regarding the pressure, rotation and even the presence of a companion star.

Stellar classification

We found that absorption lines were present in the spectra of all the stars, when the absorption spectra (which depends on temperature and indicating the presence of metals) of stars were studied, it was realised that stars could be classified into several different types called spectral classes. This classification was firstly done by Harward group of astrophysicists under the direction of E.C. Pickering and his associates. This is called Harward classification or Pickering classification. It is also called Henry Draper catalogue after the name of Henry Draper. Harward people classified the spectra of about 4,00,000 stars. It was later realised that the types of spectra varied primarily because of differing temperatures of the stellar atmospheres. Much before this the Indian astrophysicist M.N. Saha suggested that the difference in stellar spectra are principally due to surface temperatures of stars. It means that the spectral classes correspond in fact to different surface temperatures. Harward classification is done in the order of decreasing temperature. The classification, is designated by capital letters, is written as

O B A F G K M R N S H

This can be remembered by the mnemonic. Oh! Be A Fine Girl Kiss Me Right Now Sweet Heart.

The spectral types are further divided in ten subclasses beginning with 0 and ending at 9.

Among the group O group stars are hottest and H group stars are coolest. Further class A1 star is hotter than class A9 star. But A9 star is hotter than F0 star. The spectra of the hotter star of types O, B, A are sometimes referred to as early type stars while the cooler ones K, M, R, N, S, H are later type. F and G are designated intermediate type star. Our sun is a G2 star, thus it is an intermediate star.

It is interesting to note the distribution of stars throughout the galaxy. A casual glance at the stars in the night sky will give you several O and B type, a few A type, some F and G type, a smattering of K and more M types. A vast majority of stars in our galaxy over 72% of them are faint cool and red M type stars. The bright and hot O-type stars are less than 0.005%. For every O type there are about 1.7 million M-types. Now we shall briefly discuss how the spectrum are affected by temperature. We found that star is composed of 75% of hydrogen. Hydrogen emits various spectral lines such as Lyman, Balmer, Paschen, Brackett and Pfund series. For simplicity we take Balmer series for explanation. Balmer series absorption lines are obtained when electrons undergo transition from n = 2 level to higher levels. However Balmer lines do not always appear in a stars spectrum. This happen when the temperature is greater than 10,000K. At this temperature photons coming from the interior of stars have high energy that they can easily knock out electrons from hydrogen atoms. i.e, ionisation takes place. In the ionised state it cannot produce Balmer lines. Type O stars up to type B_2 exhibit no Balmer lines.

When the temperature is less than 10,000K most of the hydrogen atoms are in the groundstate. Many of the photons passing through the stars atmosphere do not have enough energy to excite electrons from ground state to energy level 2. Thus there is no Lymann absorption series in the spectra. However very few atoms in the energy level 2 can absorb the photons characteristic energy and excited to higher levels. so absorption lines are found in the spectra. Cool stars M0 and M2 are examples for this.

The principle features of spectral sequence are given in table 5 below.

Note: The Sun - A G2 star has a spectrum dominated by lines of calcium and iron.

Table 3.5: The principal features of the Harward Spectral Sequence

Spectral (star) type	Colour	Temperature	Average Mass (The Sun = 1)	Average Radius (The Sun = 1)	Average Luminosity (The Sun = 1)	Main characteristics	Examples
O	Blue to bluish white	50000 K to 30000 K	60	15	1,400,000	Lines of singly ionized helium either in absorption or emission	Naos Mintaka 10 Lacertra
B	Blue to Bluish white	30000 K to 10000 K	18	7	20,000	Lines of neutral helium in absorption	Rigel spectra (Orion)
A	White	10000 K to 8000 K	32	2.5	80	Hydrogen (H) lines are very strong for AO stars, decreasing for A stars	Vega and Sirius
F	White to Yellowish white	8000 K to 6000 K	1.7	1.3	6	Lines of Ca II are strong. Metallic lines such as iron and titanium are also seen	Procyon Canopus
G	Yellowish white to Yellow	6,000 K to 4,500 K	1.1	1.1	1.2	Lines of neutral metallic atoms (Ca II) and ions	Sun, Capella
K	Deep yellow to orange to red	4500 K to 3500 K	0.8	0.9	0.4	Absorption of lines of neutral metals and other elements	Arcturus and Aldebaran
M	Red	3500 K to 2000 K	0.3	0.4	0.04	Molecular bonds of (TiQ dominate the spectrum	Barnard, Betel-geuse and Antares

Hertz sprung-Russell (H-R) diagram

We learned that star's basic characteristics such as its radius, mass, spectral class, absolute magnitude, luminosity and temperature. Now we put all these parameters in a single graph known as Hertz Sprung-Russell diagram. It is one of the most important and useful diagrams in the study of astronomy. The H-R diagram forms the basis of the theory of stellar evolution.

In 1911, the Danish astronomer Ejnar Hertzsprung plotted the absolute magnitude of stars (a measure of their luminosities) on the vertical axis and their colours (a measure of their temperatures) on the horizontal axis. Later in 1913, the American

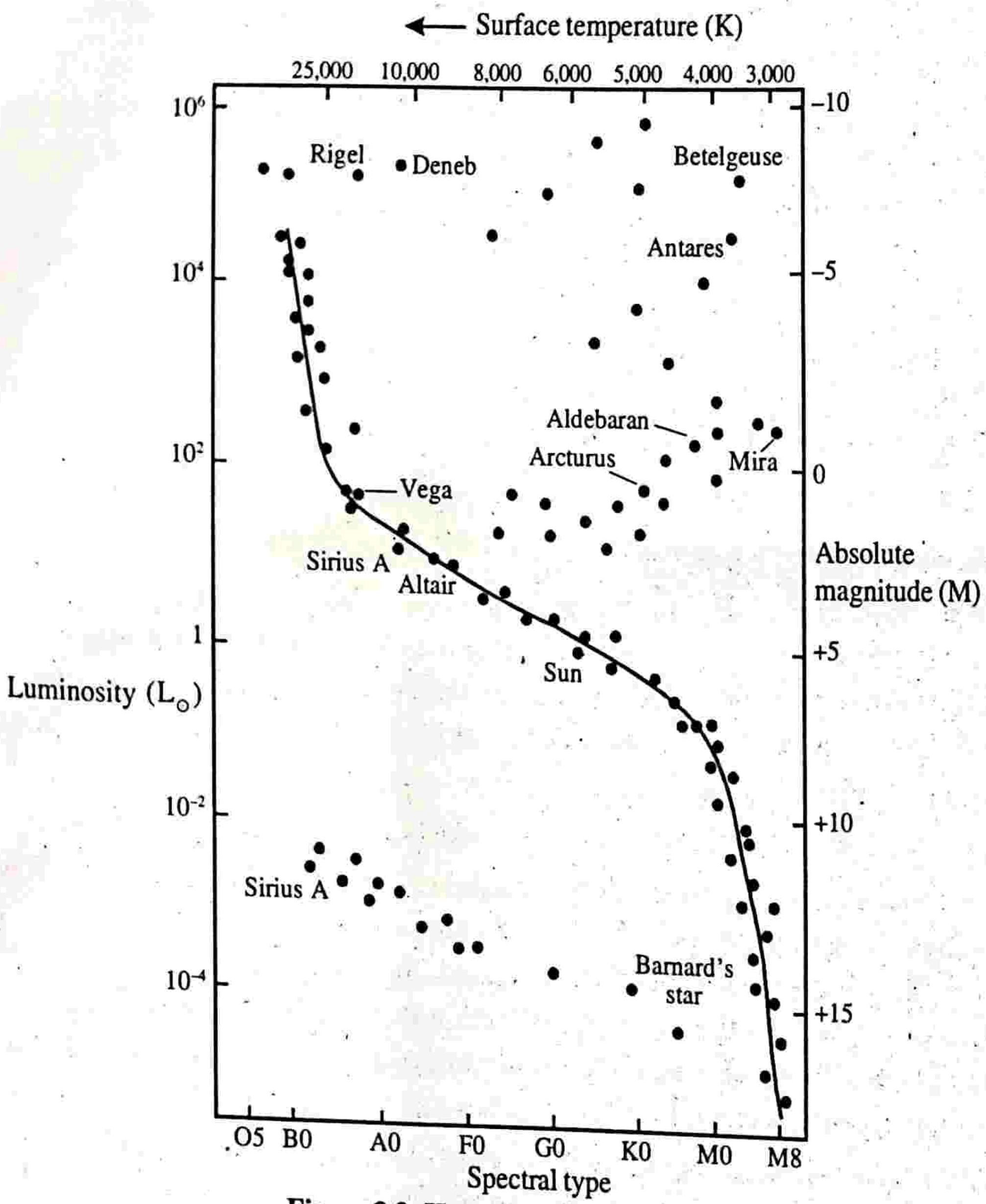

Figure 3.3: Hertzprung-Russel diagram

astronomer Henry Norris Russell independently plotted spectral types (measure temperature) on the horizontal axis and the absolute magnitude on the vertical axis. They both realised that certain unsuspected patterns began to emerge. Further more an understanding of these patterns was crucial to the study of stars. In recognition of the pioneering work of these astronomers, the graph was known as Hertz sprung-Russell diagram or H.R diagram. A plot of luminosity of stars versus their surface temperatures is known as Hertz Sprung-Russell diagram or H-R diagram. A typical H-R diagram is shown below. Each dot on the diagram represents a star whose properties such as spectral type and luminosity can be determined. Note the key features of the diagram.

(i) The temperature increases from right to left. The hot O types are on the left and cool M-types stars are on the right.

(ii) The luminosities cover a wide range, so the diagram makes use of the logarithmic scale, where by each tick mark on the vertical axis represents a luminosity 10 times larger than the prior one.

(iii) Each dot can give spectral type and corresponding luminosity in terms of Sun's luminosity.

It can be seen that stars near the upper left corner are hot and luminous. The stars near the upper right corner are cool and luminous. Stars near the lower right corner are cool and dim. Stars near the left corner are hot and dim.

H-R diagram and stellar radius

H-R diagram provides another important information about the radius of stars. This is because luminosity and temperature are related through $L = 4\pi R^2\sigma T^4$. Knowing L and T we can very well calculate the radius of stars. A graph between logarithmic luminosity along the vertical axis and temperature along the horizontal axis (temperature in the decreasing order) is plotted we get H-R diagram indicating radii of stars is given below.

From the graph following information can be drawn.

(i) Stars having same radius lie along a straight lines. (dotted diagonal lines). At a constant temperature we can see that radius increases with luminosity. As temperature decreases and radius increases luminosity is found to increase. This shows that stars in the lower most left part of the graph stars having high temperature, low luminosity and small radius, where as stars in the uppermost part having high intensity large radius but low temperature.

(ii) Stars in the lower left of the H-R diagram are much smaller in radius (about $0.01R_\odot$) and appear to be white. They are hot stars with low luminosities. They

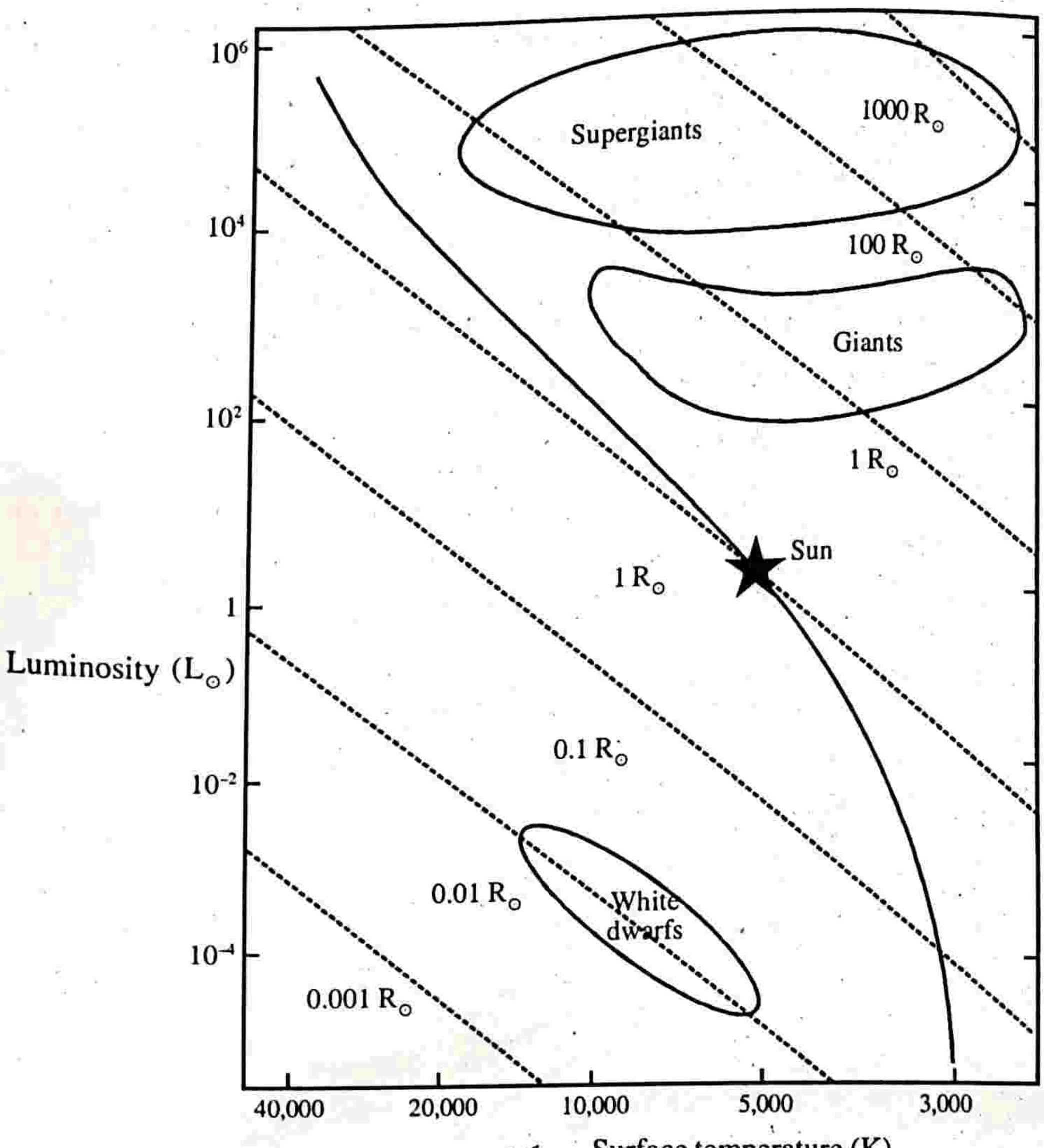

Figure 3.4: Radius of stars on H-R diagram

are called white dwarfs. They are faint stars and can be seen only through telescopes. There are no nuclear reactions in these stars but still glowing. They are remnants of giant stars. White dwarfs have approximately the same size of the earth.

(iii) Stars in the upper right are called giants. They are 10 to 100 times bigger and 100 to 1000 times luminous than the sun. They are cool stars, temperature lies between 3000 to 6000K. Many of the much cooler members of this group are reddish in colour and referred to as red giant. Arcturus in Bootes and aldebaren in taurus are red giants.

(iv) At the extreme right corner there are few stars having radii up to $1000R_\odot$. These are called supergiants. Giant and super giant make up about 1% of stars in the night sky. Antares in scorpius and Betelgeuse in orion are super giants. Their luminosity is very high.

(v) In the diagram you can see a solid line (band) stretches diagonally across it. 90% of stars in the night sky are lying in this band. These are called main sequence. The band along which most of the stars are clustered is called the main sequence. It extends from cool and dim stars in the bottom right to hot and luminous blue stars in the upper left corner. Sun is a main sequence star.

Note: For clarity dots representing stars are not shown in the graph.

H-R Diagram and stellar luminosity

The temperature of a star determines which spectral lines are most prominent in its spectrum. Therefore classifying a star by its spectral type is essentially the same

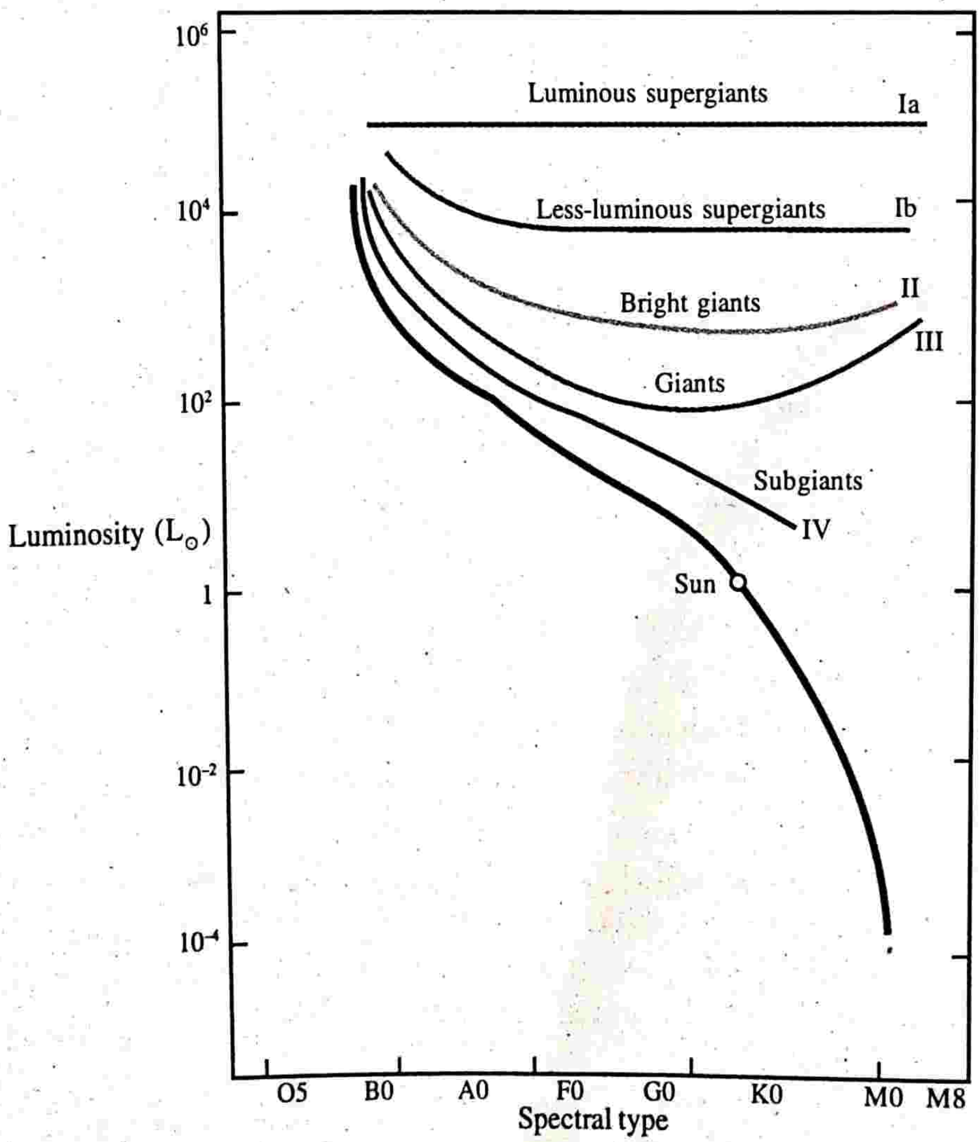

Figure 3.5: Luminosity classes

as by its temperature. The H-R diagram (L versus T) shows that stars can have similar temperatures but with different luminosities.

For example consider a white dwarf star at 7000K. At this temperature drawn perpendicular line we can see that a large number of stars such as main sequence star, a giant, a super giant etc. belong to this temperature but all are having different luminosities. Different luminosities give rise to different spectra. Therefore by examining a star's spectral lines, one can determine which category the star belongs to. Difference in spectral line means difference in the absorption lines of the spectra. It depends upon various conditions on the stars atmosphere. For example the density and pressure of hot gases in the atmosphere affect the absorption lines and hydrogen in particular. If the density and pressure are high, hydrogen atoms collide more frequently and they interact with other atoms in the gas. The collisions can use the energy levels in hydrogen atoms to shift resulting in broadened hydrogen spectral lines.

In a giant luminous star, the atmosphere will have very low pressure and density because the stars mass is spread over such an enormous volume. Therefore atoms are relatively far apart. This means that collisions between atoms are less frequent, which produces narrow hydrogen lines.

Now we draw an H-R diagram between luminosity and spectral class. Knowing both the spectral type and luminosity of a star would help an astronomer to instantly know where on the main sequence it lies. The H-R diagram is depicted below. It divides H-R diagram according to luminosity classes so that distinctions can be made between, for example, giant and super giant stars.

H-R diagram and stellar mass

H-R diagram is a graph between luminosity and temperature. Now we will see how to depict stellar masses on the H-R diagram. There are five methods mostly used for the determination of stellar masses. Mass and luminosity have been measured independently for many stars extending over a broad range of masses. It has been found that luminosity of a star is directly proportional to cube of its mass. i.e., $L \propto M^3$

It shows that luminosity strongly depends on mass. The masses of stars in the main sequence are shown in figure below. The above relation says that a star of mass $10M_{\odot}$ will have luminosity 1000 times greater than that of the Sun. Further the knowing L and M, we can predict how long a star will be in the main sequence. A star's lifetime is proportional to the mass available to burn and inversely proportional to the rate at which mass is used up.

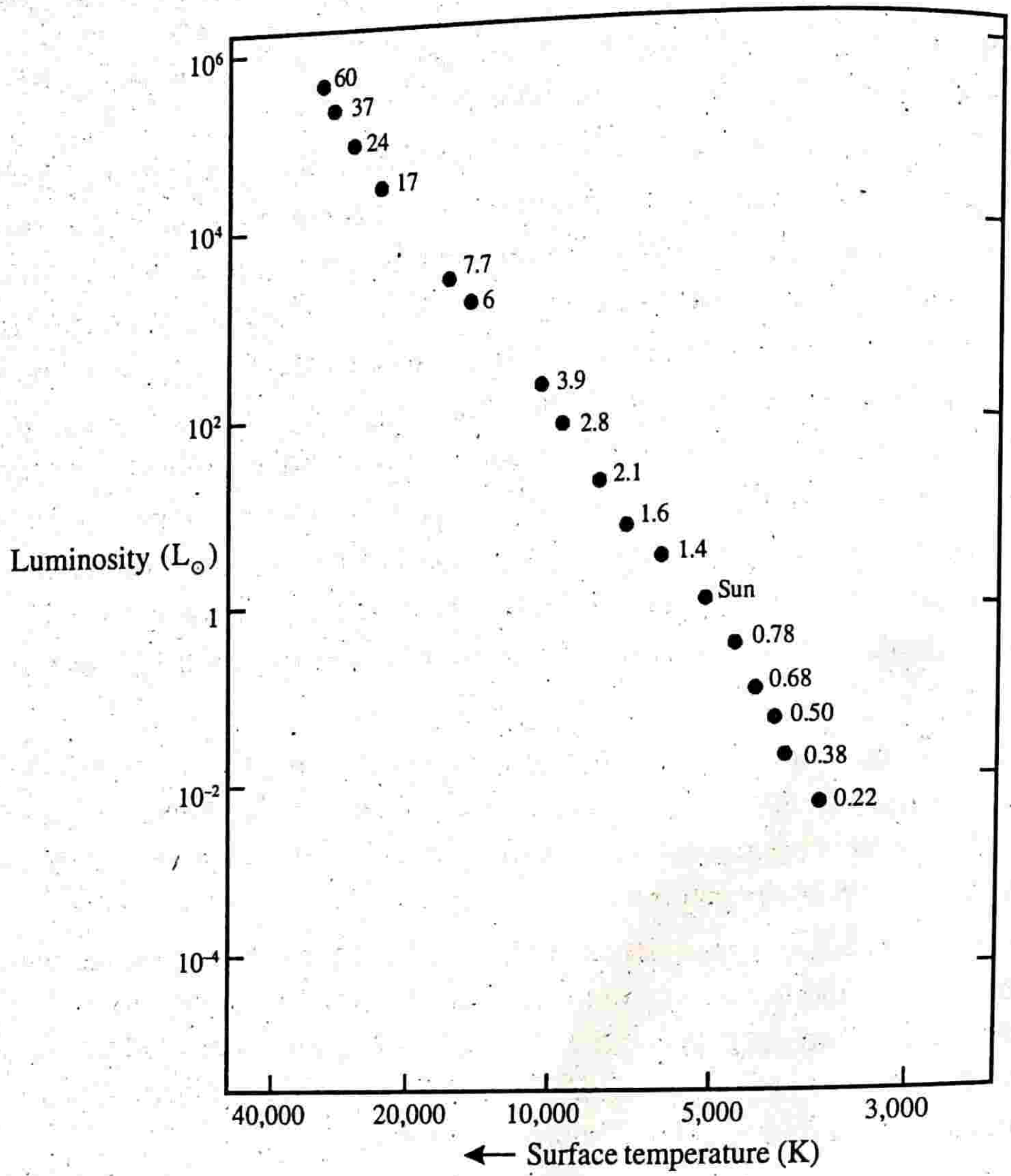

Figure 3.6: Mass and the main sequence (star's mass in terms of $M_\odot$)

i.e. $$\text{Life time} \propto \frac{M}{L} = \frac{M}{M^3} = \frac{1}{M^2}$$

$$\text{Life time} \propto \frac{1}{M^2}$$

That is life time of a star is inversely proportional to the square of its mass.

The more massive a star, the shorter its life time. Sun has a life time of 10 billion years. So a star of 10 solar mass will have a life time of 100 million years whereas the least massive stars $\left(= \frac{1}{10} M_\odot\right)$ last for trillion years.

IMPORTANT FORMULAE

1. The relation between distance and parallax

$$d = \frac{1}{p}$$

Where d is in parsecs and p is in arc seconds.

2. Relation between AU, ly and pc

(i) $1\,AU = 1.496 \times 10^{11}\,m$

(ii) $1\,ly = 9.46 \times 10^{15}\,m$

(iii) $1\,pc = 3.08 \times 10^{16}\,m$

$1\,ly = 6.32 \times 10^{4}\,AU$

$1\,pc = 2.05 \times 10^{5}\,AU$

$1\,pc = 3.26\,ly$

3. Relation between luminosity (L), apparent brightness (b) and distance d

$$L = 4\pi d^2 b$$

4. Relation between apparent brightness and magnitudes

$$m_2 - m_1 = -2.5 \log \frac{b_2}{b_1}$$

or

$$\frac{b_2}{b_1} = 10^{0.4(m_2 - m_1)}$$

5. Relation between apparent magnitude (m) absolute magnitude (M) and distance (d)

$$m - M = 5(\log d - 1)$$

6. Wien's displacement law

$$\lambda_m T = 2900000\,nmK$$

7. Flux (F), luminosity (L) and radius (R)

(i) $F = \sigma T^4$, $\sigma = 5.67 \times 10^{-8}\,Wm^{-2}K^{-4}$

(ii) $L = FA = 4\pi R^2 \sigma T^4$

8. Luminosity (L) of star is proportional to M^3

i.e. $L \propto M^3$

9. Lifetime of a star $\propto \dfrac{1}{M^2}$

UNIVERSITY MODEL QUESTIONS

Section A

(Answer questions in about **two** *or* **three** *sentences)*

Short answer type questions

1. What is astronomy?
2. What is astrophysics?
3. Distinguish between astronomy and astrophysics.
4. What is parallax?
5. What is stellar parallax?
6. Write down the relation between parallax and distance and explain the symbols used.
7. What is the limitation of parallax method?
8. Define luminosity of a star. What is its unit?
9. Define apparent brightness of a star.
10. Distinguish between luminosity and apparent brightness.
11. What are the factors on which apparent brightness depend?
12. What do you understand by magnitude of stars?
13. Write down the relation between change in magnitudes and apparent brightness of stars and explain the symbols used.
14. Distinguish between -apparent magnitude and absolute magnitude.
15. Write down the relation between apparent magnitude, absolute magnitude and distance.
16. What is the relation between colour and temperature of stars?
17. Distinguish between luminosity and flux.
18. Write down the relation between luminosity, flux and size of a star and explain the symbols used?
19. What is a star? What are its constituents?
20. What are the different spectral classes of stars?
21. Write down the spectral classes in accordance with increasing temperature?
22. Our sun is a G2 star. Explain.
23. Why astronomers study about stellar masses?
24. What are main sequence star?
25. What are the sources of energy of main sequence stars?
26. Write down three characteristics of main sequence stars?
27. What is an H-R diagram?
28. What is the importance of H-R diagram?
29. What is the relation between luminosity and mass of a star?
30. Draw an H-R diagram and indicate stellar radius.

Section B

(*Answer questions in a* **paragraph** *of about half a page to one page*)

Paragraph / Problem type questions

1. Explain stellar parallax method.
2. Discuss one method of distance measurement other than stellar parallax.
3. Obtain the relation between apparent magnitude and apparent brightness.
4. Obtain the relation between apparent magnitude, absolute magnitude and distance.
5. Obtain the relation between luminosity, flux and size of stars.
6. In an H-R diagram what are the informations that you can arrive at regarding luminosity.
7. If the parallax of the star Shravana is 0.198 arc second, calculate its distance from the earth in light year. [16.473 *ly*]
8. The distance of Bernard's star from the earth is 5.94 *ly*. Its luminosity is 1.404×10^{24} W. Find it apparent brightness. [3.53×10^{-11} Wm^{-2}]
9. The luminosity of the star Regulus is 5.46×10^{28} W, its brightness is 7.17×10^{-19} Wm^{-2}. Calculate the distance of star from the earth in parsec [25.32 pc]
10. The apparent magnitude of the star sirius A is -1.44 and that of Regulus star is $+1.36$ on the magnitude scale of stars. Calculate the relative brightness of the star Sirius A with respect to Regulus [13.18]
11. The dimmest star visible to the naked eye has a magnitude of 6. Compare its brightness with that of planet Venus whose magnitude is -4 [Venus is 10^4 times brighter]
12. The phenomenon of Nova involves the sudden outburst of a star. The star then becomes much brighter than usual for a few days. In 1995, a Nova appeared in the constellation of cygnus. In two days, the magnitude of the star changed from +15 to +2. By what factor did it brightness increase [158493]
13. The luminosity of the star Betelgeuse in the Orion constellation is 10,000 times that of the sun and its surface temperature 3000 K. Calculate the radius of the Betelgeuse with reference to that of the Sun. Take $T_\odot = 5800K$ [$R = 373.6\, R_\odot$]
14. The apparent magnitude of Aldebaren is 0.80. If it is at 21 parsecs away from the earth. Calculate its absolute magnitude. [-0.811]
15. A star whose apparent magnitude 10 is located at a distance of 32.6 *ly*. What is its absolute magnitude? [M = 10]
16. If the apparent and absolute magnitudes of Sirius B are 8.6 and 11.4 respectively. Calculate its distance in AU. [5.646×10^5 AU]
17. Find out the ranges of temperature corresponding to which a star will appear red and yellow respectively. 620 to 770 nm - red and 500 to 600 nm for yellow.

$$\begin{bmatrix} \text{For red } 3766.6 - 4677 \text{ K} \\ \text{For yellow } 4833 - 5800\text{K} \end{bmatrix}$$

18. If the luminosity of the white dwarf is 0.01 $L_\odot$ and its radius is 650 km. Calculate its temperature. $R_\odot = 6.96\times10^8$ m and $T_\odot = 5800$K [160030 K]

19. The luminosity of the Sun is 3.9×10^{26} W and the value of solar constant on the surface of earth is $1388 Wm^{-2}$. Calculate the distance of earth from the Sun. [1.495×10^{11} m]

20. Suppose the Sun is taken from its present position which is at a distance of 1.496×10^{11} m from the earth to a new position located at 4 light years from earth. Calculate ratio of the apparent brightness of the Sun in the new position to the actual position.

[1.56×10^{-11}]

Section C

(Answer questions in about **one** to **two** *pages)*

Long answer type question (Essay)

1. Sketch an H-R diagram and write down all informations that we obtain from it.

Hints to problems

1 to 6 See book work

7. $d = \frac{1}{p}$, $p = 0.198$ d will be in parsec. $1\text{pc} = 3.26ly$

8. $b = \frac{L}{4\pi d^2}$ $L = 1.404\times10^{24}$, $d = 5.94\times9.46\times10^{15}$

9. $L = 4\pi d^2 b$ $\therefore$ $d = \left(\frac{L}{4\pi b}\right)^{\frac{1}{2}}$

10. We have $m_2 - m_1 = 2.5\log\frac{b_1}{b_2}$, $m_2 = 1.36$, $m_1 = 1.44$ get the result

11. Use $m_2 - m_1 = 2.5\log\frac{b_1}{b_2}$ find $\frac{b_1}{b_2}$

12. Use $m_2 - m_1 = -2.5\log\frac{b_2}{b_1}$

$m_1 = 15$, $m_2 = 2$ find $\frac{b_2}{b_1}$

13. $$L = 4\pi\sigma R^2 T^4$$

$$L_{\odot} = 4\pi\sigma R_{\odot}^2 T_{\odot}^4$$

$$\therefore \quad \frac{L}{L_{\odot}} = \frac{R^2}{R_{\odot}^2}\frac{T^4}{T_{\odot}^4}$$

$$\therefore \quad \frac{R}{R_{\odot}} = \left(\frac{L}{L_{\odot}}\right)^{\frac{1}{2}}\left(\frac{T_{\odot}}{T}\right)^2, \quad \frac{L}{L_{\odot}} = 10^4$$

$$\frac{T_{\odot}}{T} = \frac{5800}{3000} = 1.933, \quad \text{find } \frac{R}{R_{\odot}}$$

14. $m - M = 5(\log d - 1)$

$$m = 0.80, \ d = 21 \text{ parsec}, \ \text{find M}$$

15. $m - M = 5(\log d - 1)$ $m = 10$, $d = \dfrac{32.6}{3.26}$ pc Find M.

16. $m = 8.6$, $M = 11.4$

Using $m - M = 5(\log d - 1)$, $d = 2.754\text{pc}$. $d = 2.754 \times 2.05 \times 10^5 \text{AU}$

17. Use $$\lambda_m T = 2900000\text{nm}$$

$$T = \frac{2900000}{\lambda_m}\text{nm}$$

For red $$T = \frac{2900000}{620} = 4677.4\text{K}$$

$$T = \frac{2900000}{770} = 3766.6\text{K}$$

For yellow $$T = \frac{2900000}{500} = 5800\text{K}$$

$$T = \frac{2900000}{600} = 4833\text{K}$$

18. $L_w = 4\pi\sigma R^2 T_w^4$

$$L_{\odot} = 4\pi\sigma R_{\odot}^2 T_{\odot}^4$$

$$\frac{L_w}{L_{\odot}} = \left(\frac{R_w}{R_{\odot}}\right)^2 \left(\frac{T_w}{T_{\odot}}\right)^4, \quad \frac{L_w}{L_{\odot}} = 0.001 = \frac{1}{100}$$

$$\frac{R_w}{R_{\odot}} = \frac{650\times10^3}{6.96\times10^8} = 93.39\times10^{-5}$$

Calculate T_w

19. Use $L = F\times 4\pi d^2$, $\quad F = 1388\,\text{Wm}^{-2}$(given)

$$d = \left(\frac{L}{F4\pi}\right)^{\frac{1}{2}} = \left(\frac{3.9\times10^{26}}{1388\times4\times3.14}\right)^{\frac{1}{2}}$$

20. $L = 4\pi d^2 b$

$L_{\odot} = 4\pi d_{\odot}^2 b_{\odot}$ $\quad L_{\odot} = 4\pi d_{\odot}'^2 b_{\odot}'$, equating we get

$$\frac{b_{\odot}'}{b_{\odot}} = \frac{d_{\odot}^2}{d_{\odot}'^2} = \left(\frac{1.496\times10^{11}}{4\times9.46\times10^{15}}\right)^2 = 1.56\times10^{-11}$$